ASGSR 2016

# Biomechanical Modeling of Split-leg Squat and Heel Raise on the Hybrid Ultimate Lifting Kit (HULK)


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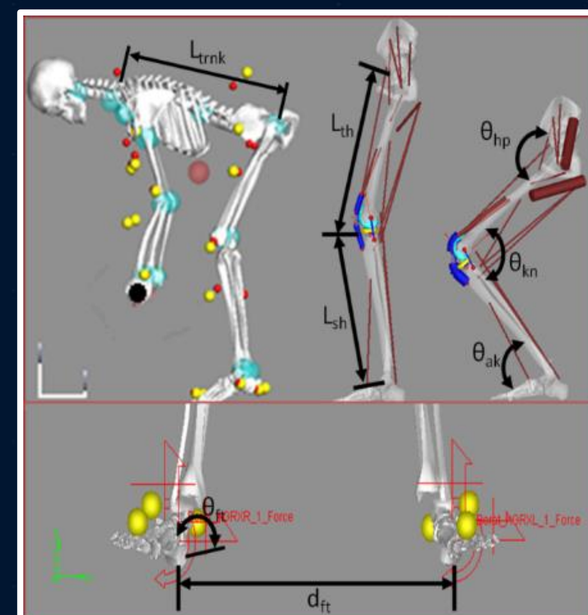
# Digital Astronaut Project – Load Configuration

- Same subject, objectives and methods as the preceding Gallo presentation
- These exercises
  - Split-leg squat (SLS)
  - Heel Raise (HR) (still in progress)
- Load configuration analysis is the primary focus of this presentation
- We also have data available for stance and cadence variations

# Exercises and Load Configurations

How does the loading method affect localized physiological outcomes on HULK for exercises of interest?

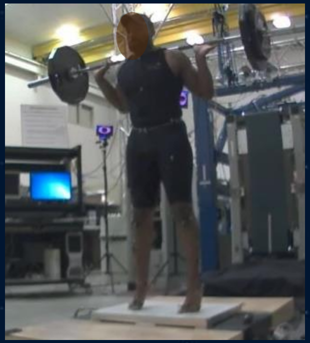
Split-leg squat (SLS)

Free weight
"Gold standard"

HULK
Long Bar

HULK
Harness*

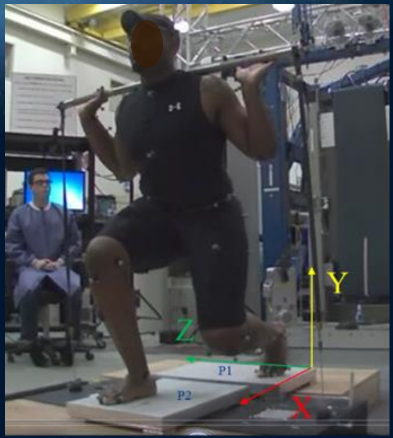
HULK
T-Bar

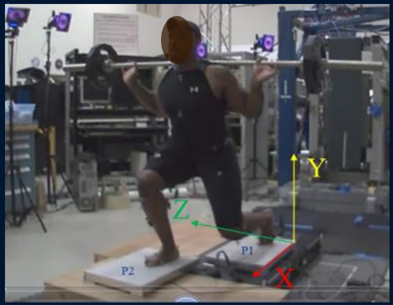


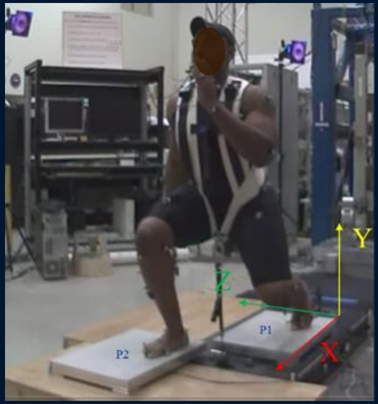
Heel Raise (HR)

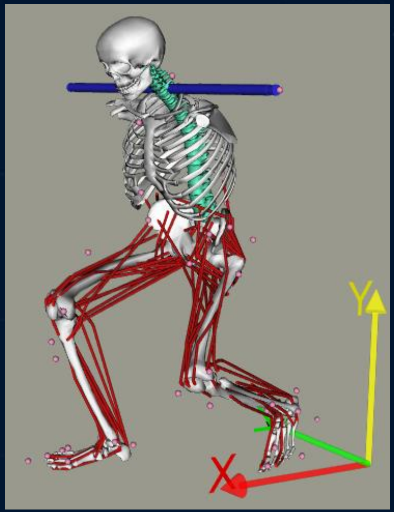
* Yo-yo Technologies
http://www.yoyotechnology
com/products/yoyo-squat/

# Major Findings for SLS



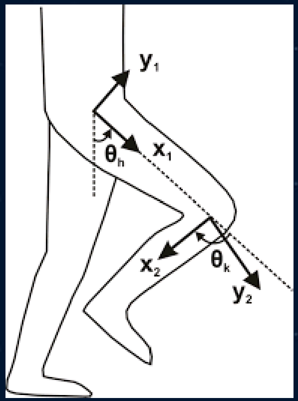



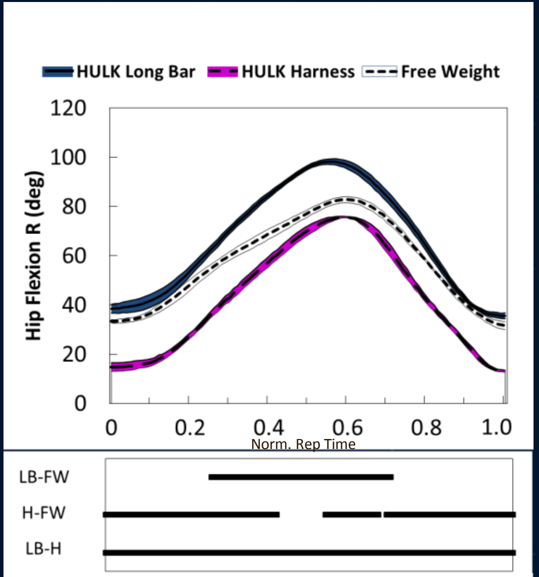
# Comparison of Live Video and OpenSim Model Kinematics for SLS

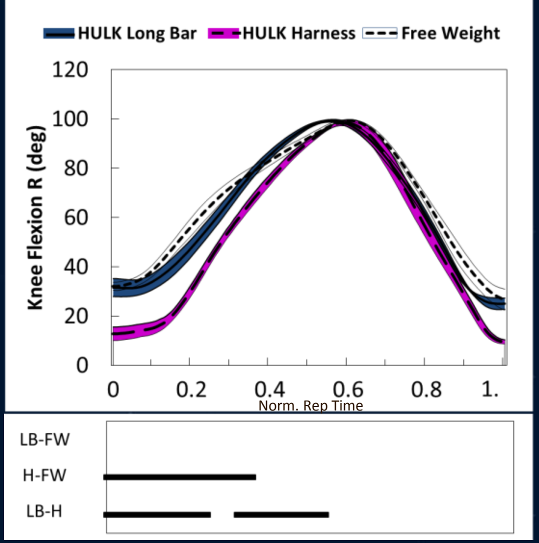
# SLS Load Configuration Analysis - Kinematics

Hip




Knee



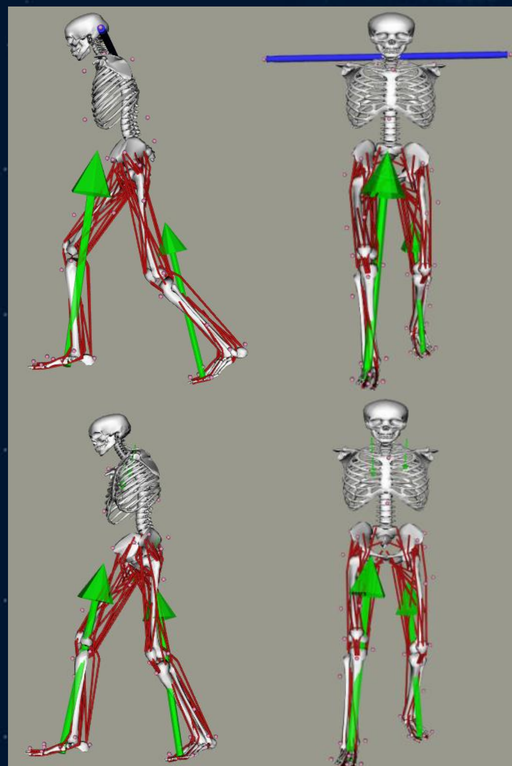




- Harness posture is more “upright” vs. long bar
  - Less hip and knee flexion over the course of the rep
- Hip abduction (not shown) remains <10 deg for all three load cases throughout the movement

# SLS Load Configuration Analysis – Ground Reaction Forces

Long Bar

Harness

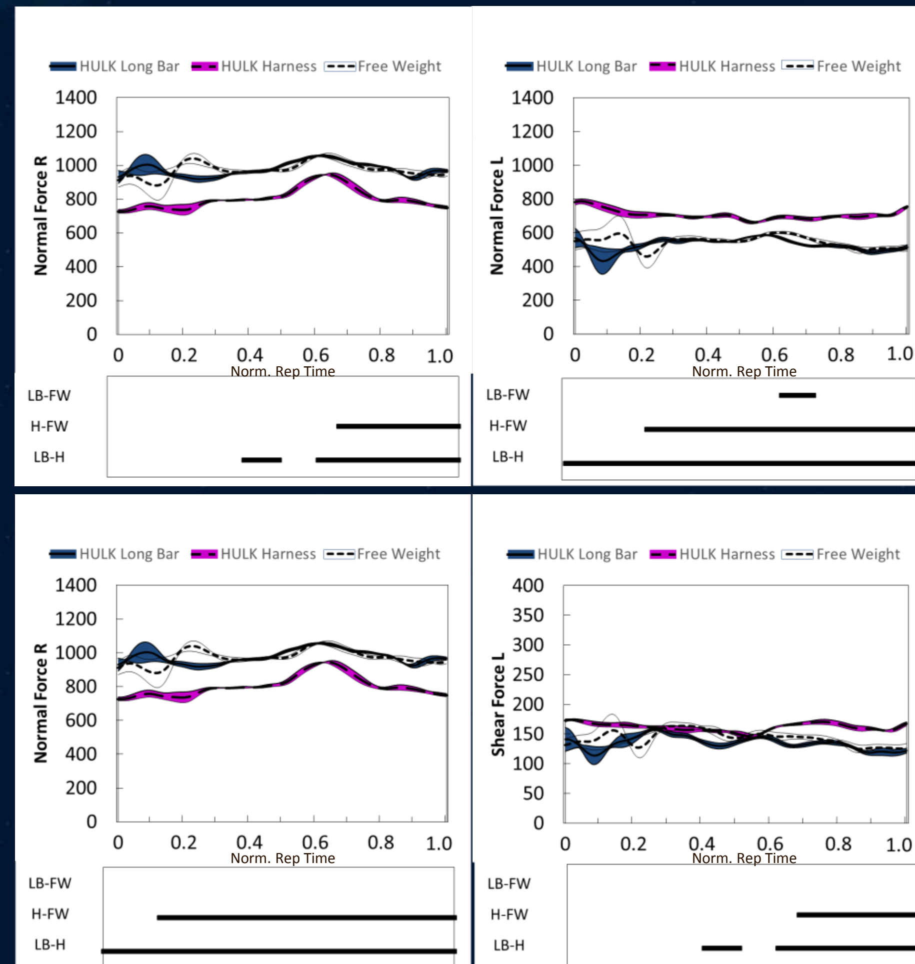


Target Leg

Back Leg

Normal

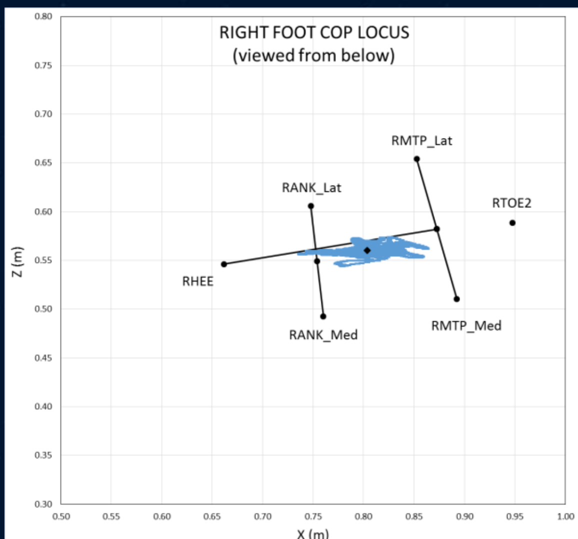
Shear



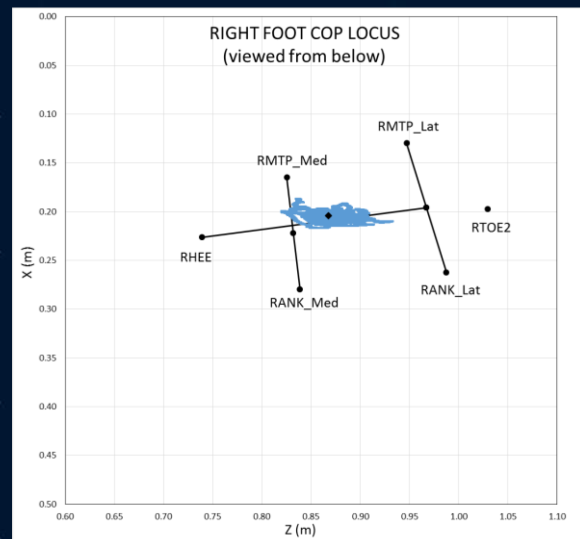

- Harness shifts the subject's load distribution more onto the back foot relative to both long bar and free weight
- Shear forces are higher with the harness

# SLS Load Configuration Analysis – Centers of Pressure Loci in Target Foot

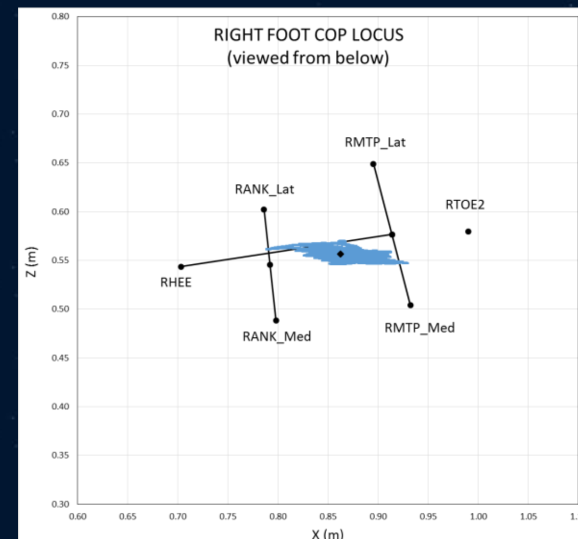
Free Weight




Long Bar



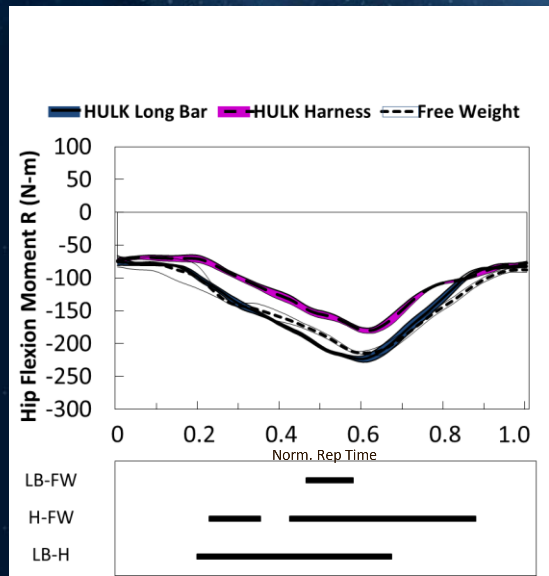

Harness

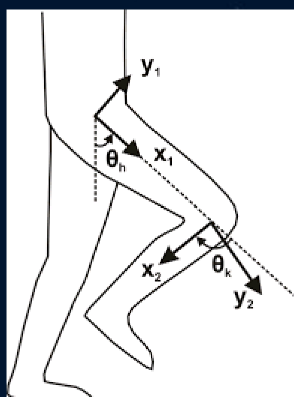



- Long Bar COP locus shifts more laterally toward mid-foot vs. free weight
- Harness COP locus shifts more forward (toward toe) and slightly more medially vs. free weight and long bar

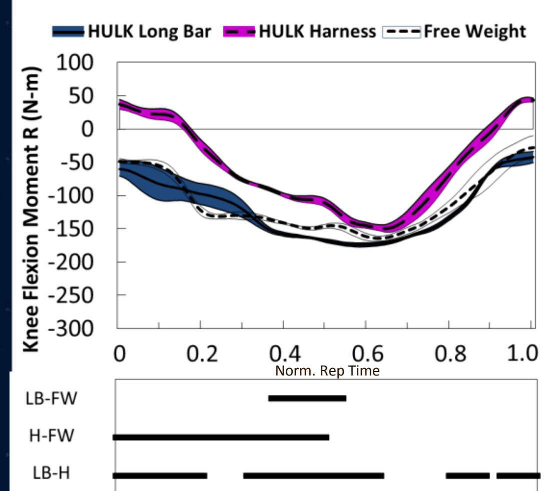
# SLS Load Configuration Analysis – Joint Torques (Inverse Dynamics)

Hip




Knee



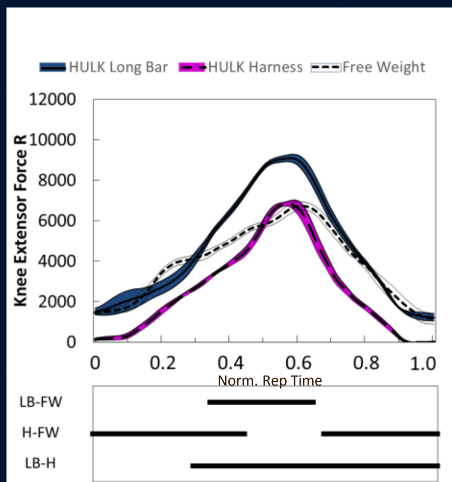

- Harness exercise produces less hip and knee torque vs. long bar over the course of the rep
- Long bar vs. free weight exhibits only minor differences

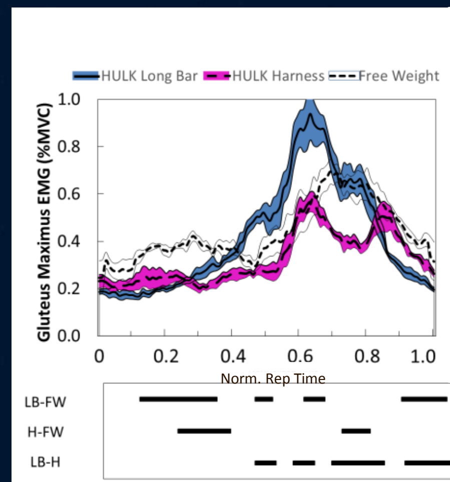
# SLS Load Configuration Analysis – Kinetics: Hip Muscle Forces and EMG

Muscle Forces

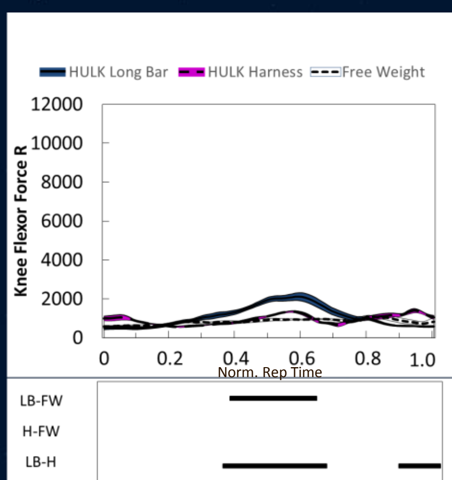
EMG Envelope

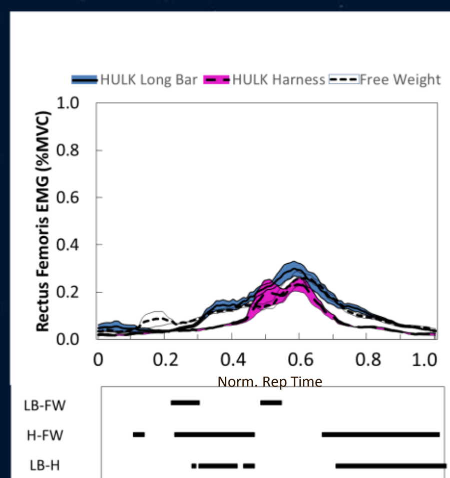
Hip Extensors (Glutes)




Hip Flexors (RecFem)



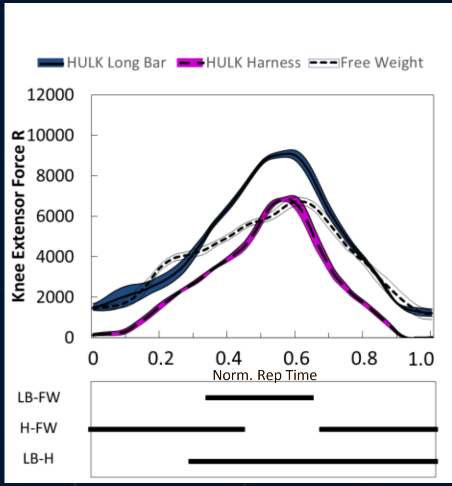

- Harness reduces estimated muscle forces in agonist muscles
- Consistent with reduction in target leg GRF, joint torque and EMG responses
- MVC normalizations differ among trials since data were acquired on different days

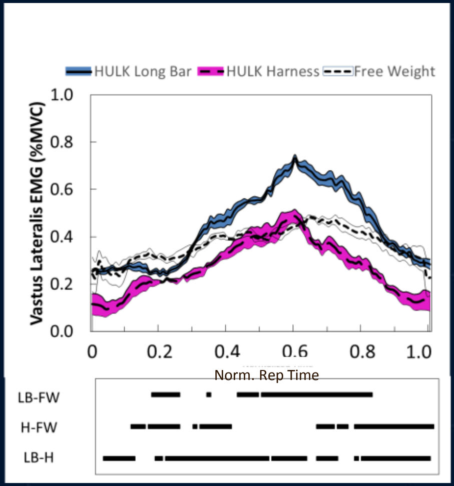
# SLS Load Configuration Analysis – Kinetics: Knee Muscle Forces and EMG

Muscle Forces

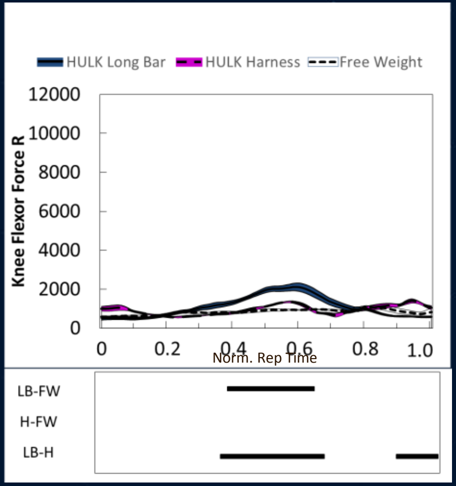
EMG Envelope

Knee Extensors (Quads)




Knee Flexors (Hamstrings)



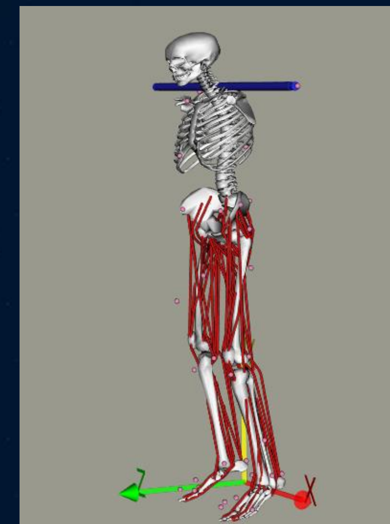

No data

- Free Weight appears to activate the knee extensors earlier in the lift.
- Harness case shows much less hip extensor activation than the bar cases.
- Harness case shows more uniform knee flexor activation over the course of the lift.

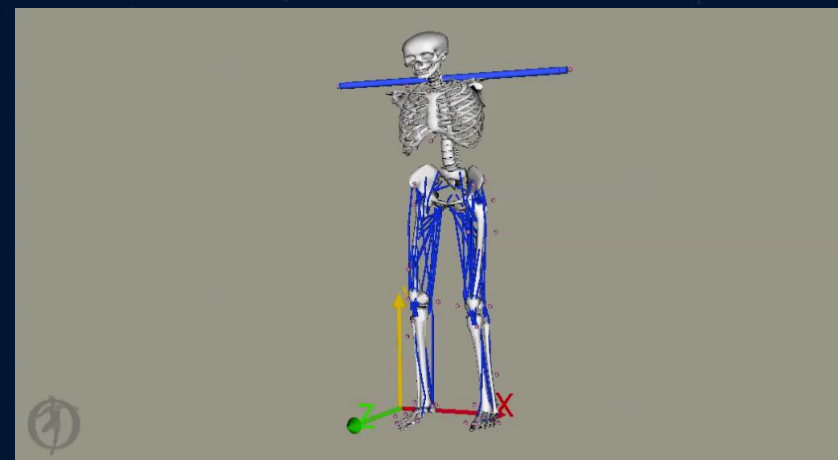
# Discussion of SLS findings to date

- Using the harness (vs. long bar):
  - The subject places more weight on the non-exercising leg and shear GRFs increase
  - COP shifts more forward and medially in the target foot
  - A small (<50 N-m) knee flexion moment occurs in the exercising leg at the top of the movement
  - Range of motion increases (+15% ) at both hip and knee joints
  - Peak joint moments decrease in the hip (-29%) and knee (-6%)
  - Peak hip extensor (-37%) and knee extensor (-8%) muscle forces decrease
- These single-subject results suggest that exercise at a higher applied load with the harness may be needed to impart the same exercise stimulus as with the long bar.
- Modeling can help to quantify this difference in other subjects

# Preliminary Findings for Heel Raise

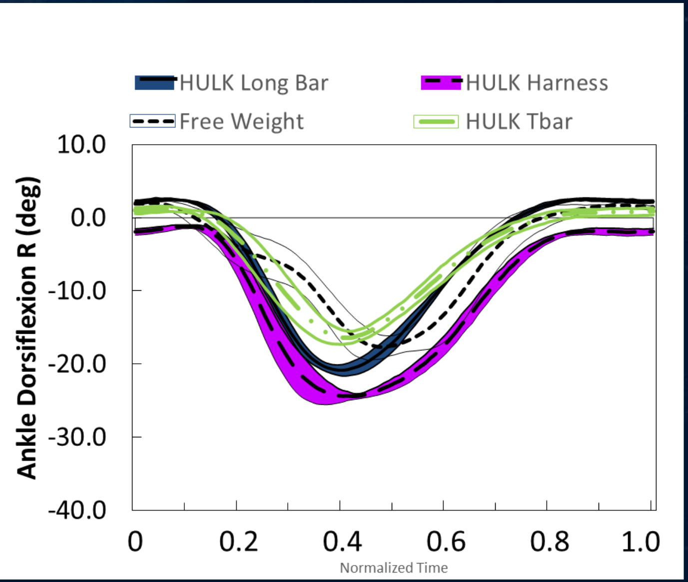
# Comparison of Live Video and OpenSim Model Kinematics for Heel Raise

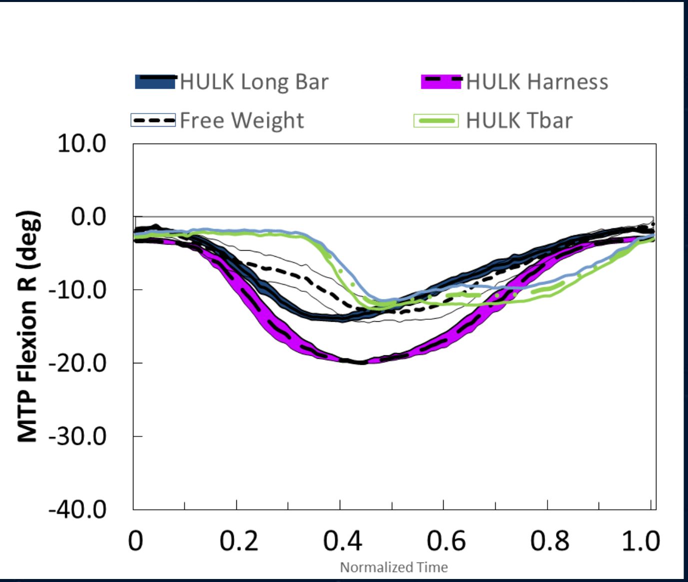


- Only kinematic and EMG results will be presented here
- Some key single-tether data are still needed to complete the analyses
- Plan to acquire data in Nov 2016

# HR Load Configuration Analysis - Kinematics

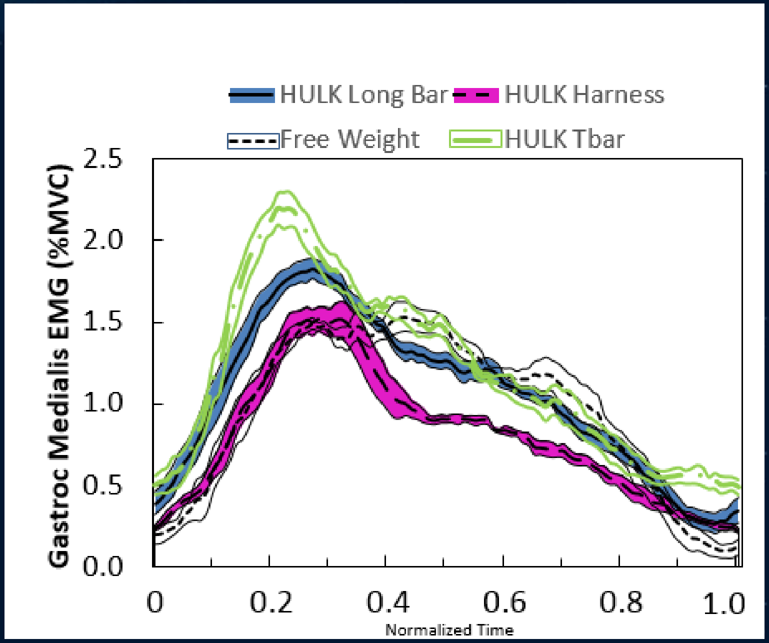
- Ranges of motion in the ankle and MTP joint are general highest for the harness
- The subject adopted a motion to lengthen the free weight and T-Bar concentric phases vs. the long bar and harness concentric phases
- There is a noticeable hesitation followed by a punctuated movement when using the T Bar



# EMG Comparison for HR

- The shape of the gastrocnemius activation profile is relatively consistent across loading configurations
- MVC normalizations differ among trials since data were acquired on different days



# Looking Forward

- Plan to publish load configuration analysis findings when complete
- Incorporate deadlift findings into load configuration analysis (Jagodnik)
- Will continue modeling efforts to inform and support the development of exercise countermeasure devices on NASA deep space missions
- Incorporate predictive models to provide kinematic estimations for situations where motion capture is impractical (e.g., microgravity)

# Questions?

**Thank you for listening!**

# Problem Statement

- Given the small size of the MPCV exercise device, will it be able to provide sufficient physiological loading to maintain musculoskeletal performance?

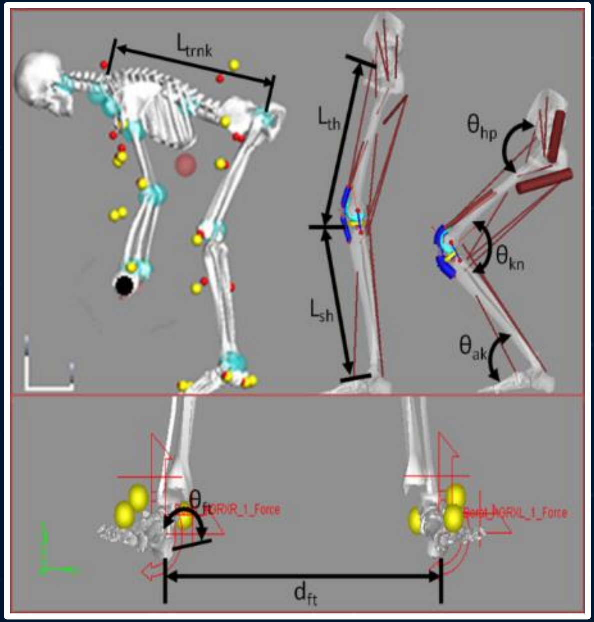
- Advanced Exercise Concepts Project Risk:
  - Single-tether design may limit exercise performance (?)

- Advance Exercise Concepts Project Requirement:
  - The device shall allow the crew member to perform squat, deadlift and heel raise exercises with proper body positioning*

*according to JSC-29558, “Resistive Exercise Description Document”

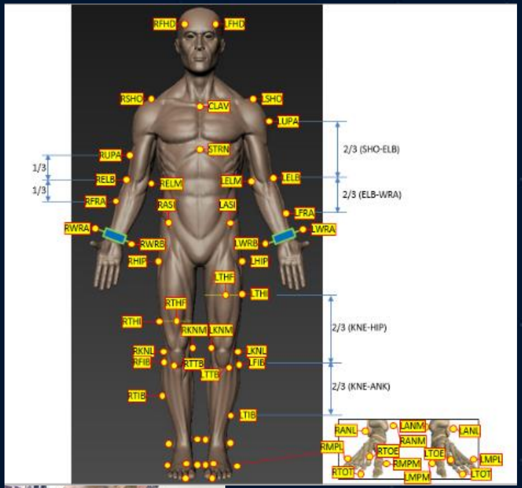
# Biomechanical Modeling and Simulation (M/S)

- Human exercises/movements
- Primarily resistance training
  - Regular squat (SQ)
  - Split-leg squat (SLS)
  - Heel-raise (HR)
  - Deadlift (DL)
- Using measured input data
  - Motion history (kinematics)
  - Applied forces
    - Ground Reaction Forces (GRF)
    - Device loads
  - Subject's anthropometrics
- Estimate outcomes
  - Muscle forces and moment arms
  - Joint torques
  - Mechanical loads (bones/joints)

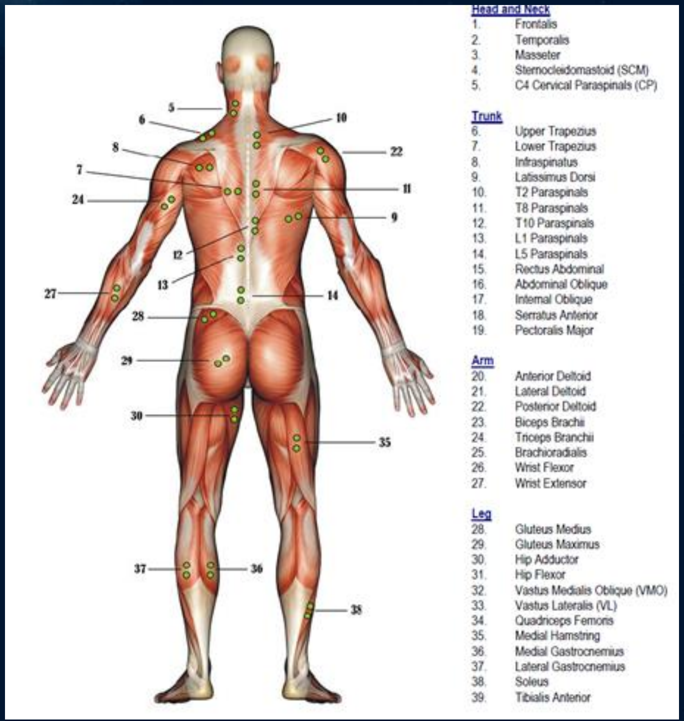
# Methods: Data Collection

- GRC Exercise Countermeasures Lab (ECL)
- 3 sessions: APR, JUL, OCT 2015
- Mocap, EMG and force data are synced.
  - Motion capture: BTS Smart-D®, 12 camera system, 100 Hz sampling
  - Ground Reaction Forces (GRF): Kistler® Model 9261 force plates, 100 Hz sampling
  - Device loads: load cells internal to HULK
- EMG: BTS FreeEMG 16 wireless sensors
  - 1000Hz sampling
  - Band pass filtered 20-450 Hz
  - Full wave rectified, RMS envelope
  - MVC normalized
- 1 subject for this data set



# Methods: EMG

| Sensor | Muscle location |
|---|---|
| Blue 1 | Tibialis Anterior |
| Blue 2 | Vastus Medialis |
| Blue 3 | Rectus Femoris |
| Blue 4 | Vastus Lateralis |
| Blue 5 | Hip Adductors |
| Blue 6 | Rectus Abdominis |
| Blue 7 | External Obliques |
| Blue 8 | Medial Gastrocnemius |
| Red 1 | Lateral Gastrocnemius |
| Red 2 | Semitendinosus |
| Red 3 | Biceps Femoris |
| Red 4 | Gluteus Maximus |
| Red 5 | Multifidus |
| Red 6 | Longissimus |
| Red 7 | Middle Trapezius |
| Red 8 | Upper Trapezius |




- EMG Processing
  - Sampling rate = 1000 Hz
  - Band pass filtering: 20 to 450 Hz,
  - Full-wave rectified and enveloped with RMS calculation
  - EMG activation levels (0.0 to 1.0) normalized to the subject's MVC
  - MVC tests were performed prior to application of the mocap markers.
    - Muscles isolated for testing according to: Hislop HJ, Avers D, Brown M, Daniels and Worthingham's Muscle Testing: Techniques of Manual Examination and Performance Testing, 9th Edition, Elsevier Saunders, St. Louis, MO, 2014.

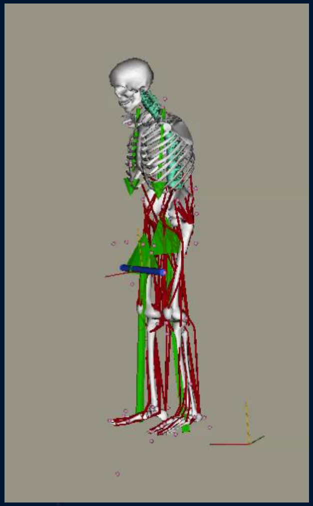
# Methods: Biomechanical Models in OpenSim

- OpenSim (Stanford Univ.) is freely available biomechanical simulation software allowing users to
  - Develop models of musculoskeletal structures
  - Create dynamic simulations of movement and kinematics
  - Calculate estimates for muscle and joint kinetics
- Used a modified and scaled version of the Rajagopal* (2016) lower body model from OpenSim

*Rajagopal, A., Dembia, C.L., DeMers, M.S., Delp, D.D., Hicks, J.L., and Delp, S.L., "Full body musculoskeletal model for muscle-driven simulation of human gait," (in review, submitted to IEEE Transactions on Biomedical Engineering) (2016).

Long Bar HR

Harness Squat



T-Bar Heel Raise

# Methods: OpenSim Work Flows

For detailed explanation of the workflow steps, refer to the OpenSim User's Guide.
http://simtk-confluence.stanford.edu:8080/display/OpenSim/User%27s+Guide

**Model Scaling**

Match the model to the subject's anthropometric measurements

**Inverse Kinematics (IK)**

Compute the joint angles that best replicate the marker position history

**Inverse Dynamics (ID)**

Determine the net joint forces and joint torques based on kinematics

**Static Optimization (SO)**

Extend ID to resolve the net muscle group forces at each instant in time

EMG
Validation

(iteration among steps is assumed)

# Methods: Statistical Analysis in Matlab

- Determine rep start and stop times from a marker trajectory
- Resample outcomes onto a normalized time vector from 0.0 to 1.0
- Compute ensemble average
- Perform statistical analysis at each increment (μ and σ)